

T-1

Mechanics of Materials & Equation-of-State

Tensile Strength of an Interface

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Even when fabricated under controlled laboratory conditions, with low-impurity concentrations, high-resolution electron microscopy routinely reveals a complex interfacial zone separating two bonded materials. For example, the interfacial zone between diffusion-bonded FCC Cu and FCC MgO, because of a 14% lattice mismatch, is characterized by a hexagonal dislocation structure caused by the interpenetration of the two atomic lattices. Because of these complications, *ab initio* calculations done on materials separated by *ideal* interfaces tend to grossly overestimate the tensile strength of an interface. (The tensile strength is the normal-directed stress required to completely overcome the interfacial adhesion between two bonded materials.) Thus, while of pedagogical interest, the results generated by these *ab initio* calculations are of limited use for practical applications.

The strength of an interface between two bonded materials is of great technological interest. It is of central importance in composite material research: it is well known that interfacial damage in a composite will compromise its performance. Further, the ability to measure the strength of an interface is a central requirement in thin film technology. Because of its technological importance, we are currently developing a joint experimental and theoretical technique that can be used

to measure the interfacial strength for a host of different interfacially-bonded systems.

The experimental technique is based on the Laser-Driven Miniflyer, which is a device used to measure the properties of materials under shock-wave conditions. As shown in Figure 1, a pulsed Nd:YAG laser is focused through a transparent substrate onto a thin multilayer that has been deposited on the substrate. The “flyer” is a thin foil placed on the multilayer. Upon absorbing the energy from the laser pulse, a plasma is created in the multilayer which accelerates the flyer into a target material. In Figure 1, the target is a

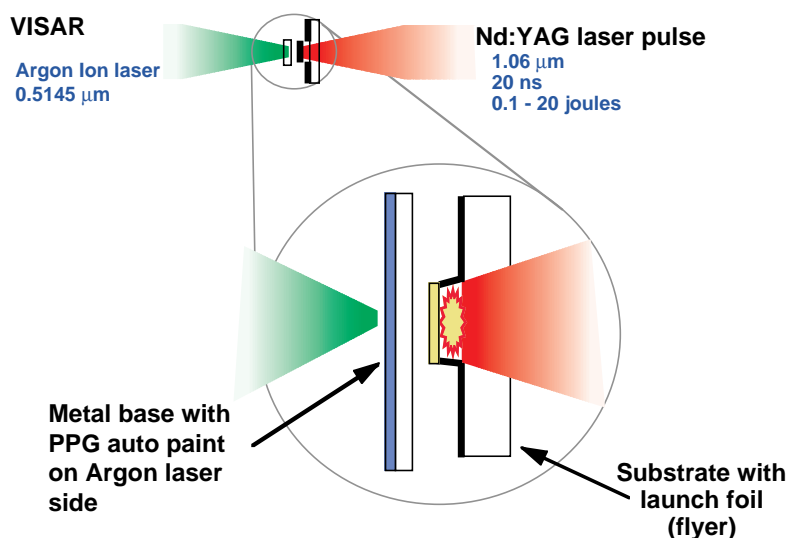


Figure 1

thin layer of paint adsorbed to an aluminum substrate. (This particular system is one of interest to PPG Industries.) It is possible to achieve compression and tension waves of substantial magnitude with this setup. By properly designing an experiment, the tensile wave can be used as a mechanism to fracture an interface. A high-resolution velocity interferometer (VISAR) is used to measure the particle (material) velocity at the outer free surface of the target.

The success of this approach is contingent on the simultaneous development of a theoretical analysis to be used to extract the interfacial strength from information contained in the experimental data. The goal of

the theoretical analysis is to simulate the shock-wave as it propagates in the system. This is done by using conservation of mass, momentum, and energy in the form of continuum equations (the common misnomer for these are the hydrodynamic equations), plus the relevant constitutive relations for the materials (such as linear elasticity, plasticity, viscoelasticity, and interfacial information). In Figure 2, we show an example of the theoretically-determined tensile wave as it passes through an interface in a bilayer system. The primary advantage of this method, over other methods, is seen from the figure — at a given instant in time, the tensile wave is highly localized in space. In other quasi-static testing methods, the strain fields produced during the process of debonding an interface extend over the entire length of the sample material. In those experiments, it is difficult to separate the mechanical response of the interface from that of the bulk materials.

In Figure 3, the particle velocity measured by VISAR in the Laser-driven Miniflyer experiment, and that produced by the theory, are compared. In this example, the target is again the paint-aluminum system. By adjusting parameters in the interfacial model, the depth of the first minimum in the theoretical particle velocity profile can be made

to coincide with the experimental velocity profile. In doing so, a reliable estimate of the tensile strength of the interface can be deduced.

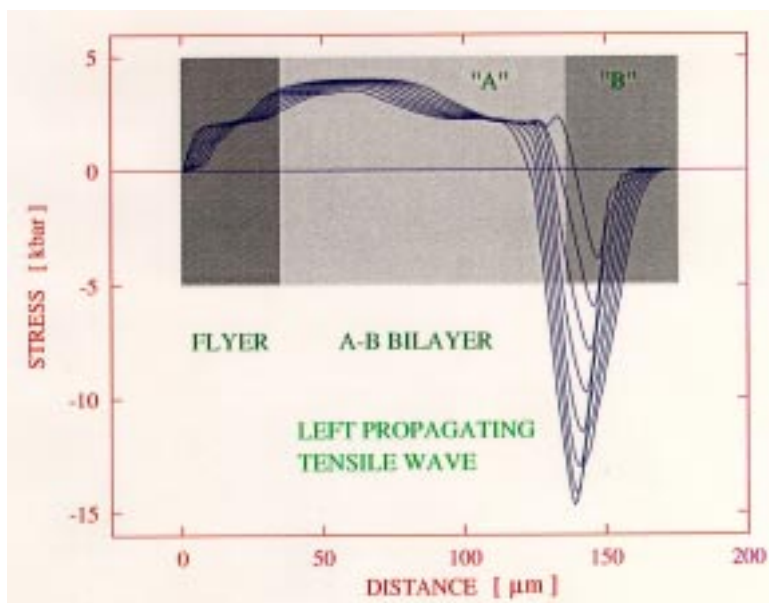


Figure 2

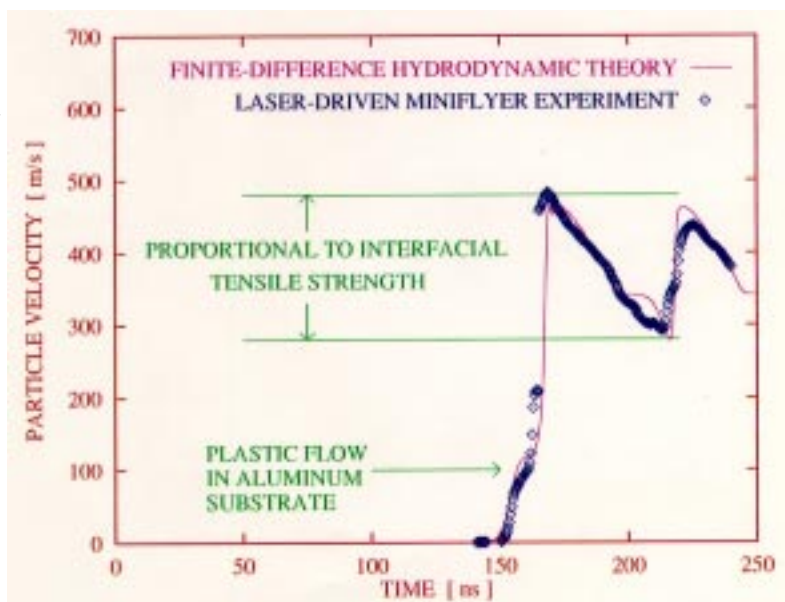


Figure 3